12-1-2011

Airport Solar and Geothermal Power

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AIRPORT SOLAR AND GEOTHERMAL POWER

by

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Bachelor of Science, University of North Dakota, 2008

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota
December
2011

This thesis, submitted by Raymond D. Mills in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

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Department	Aviation
Degree	Master of Science

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ABSTRACT

This research study has been developed to understand how solar and geothermal energy systems are being utilized by airports throughout the United States. There is currently little specific research on this topic. As fuel prices continue to rise and sources of non-renewable energies begin to be unavailable and become economically unviable, it is important that industries such as aviation continue to look toward clean, renewable sources of energy.

A survey was developed and distributed to 178 airports throughout the United States to determine adoption rates of solar and geothermal energy systems and a host of other variables that are likely to have an impact on those adoption rates. It was the goal of the study to determine which factors favorably lead to adoption of these promising energy technologies and use that data to provide additional insight for other airports to consider with regards to environmentalism.

CHAPTER I

INTRODUCTION

Background Information

Commercial aviation is an industry that is deeply intertwined with the world economy. It is difficult to imagine a world without the ability to travel hundreds of miles in only a few hours and deliver packages almost anywhere. Within the United States, total profits related to commercial aviation in 2009 amounted to approximately $1.196 trillion, with revenue approximately $360 billion (Federal Aviation Administration, 2011). These values represent 5.2% of the United States' Gross Domestic Product (GDP) (Federal Aviation Administration, 2011). A system as important as aviation requires a sufficiently developed infrastructure in order to succeed and airports are arguably the most important piece of that infrastructure. Airports range in size from tiny landing strips to the very large, multiple runway facilities like Los Angeles International. Despite their differences in size, all airports share a need to conduct operations as efficiently and economically as possible. Energy consumption by airports has become an important issue as a result of rising fuel costs and the increasing awareness that current methods of power generation are in need of replacement by cleaner and renewable sources.

Environmentalism is a key issue in today's world. The gas shortage during the early 1970's was the first in a series of wake-up calls for Americans that our supply of fossil fuels is finite and will be exhausted some day. Sadly, though, the overall response to the issue of finite supply has been slow. The lack of proper surveying tools and methods, a lack of full public support and the exponential growth of the world's population has meant that resources are being consumed at an ever greater rate (Kreith & Kreider, 2011). Since the industry's humble beginnings in 1903, the aviation industry has become a vital part of the world's economy. It has grown tremendously throughout the past century and total passengers flown in the United States alone has grown to around 800 million per year, peaking at over 835 million in 2007 (Bureau of Transporation Statistics, 2010). Despite the economic recessions that occurred during the 2000's, many economic and industry experts are predicting air travel to continue to rise a great deal in the next ten to twenty years (Federal Aviation Administration, 2011).

Such growth in passenger demand means that airports around the world will need to manage and update facilities in order to meet those demands. New terminals will need to be constructed; existing terminals will require renovation and other facilities expanded. With each expansion comes the potential of increased energy usage, but also the potential to offset or reduce such usage. Even airports that do not expand will still need to contend with the fact that more passengers will mean more resource use. For example, one of the leading ways in which airports will expend energy is through air conditioning. All else remaining equal, more passengers passing through the airports buildings means more warm bodies, and thus a greater cooling requirement.

Airports are complex entities that partake in a wide variety of activities. As such, the diversity of building types at large airports can be extensive. Airports, especially large, international airports, also vary greatly in their design; however, all of these facilities must consume energy in order to operate. Most airports also share similar characteristics, being flat with an abundance of open ground and lack of tall structures. These characteristics come into play when discussing how to better utilize energy at an airport (Ruther & Braun, 2009).

When discussing the issue of energy use it is important to understand where that energy comes from and how it is produced. Within the United States, energy is produced by a wide variety of means. Wind, solar, nuclear, natural gas, geothermal, coal, oil, hydroelectric, wood and biomass are all ways in which electricity is generated. Of all the many different forms of electricity generation, the two most significant sources come from natural gas and coal. These two forms of electricity generation account for about 71.7% of the total rated electrical capacity within the United States (U.S. Energy Information Administration, 2010). Wind and solar, on the other hand, represent only 2.3% of the total energy production in the U.S. (U.S. Energy Information Administration, 2010).

Statement of the Problem

The United States' current means of energy production is heavily reliant on non-renewable sources of energy (U.S. Energy Information Administration, 2010). As such, there is the acute realization that at some point in the future these non-renewable sources of energy will no longer prove to be economically viable or even available. For many sources of energy, like petroleum, this point is sooner rather than later (Czucz, Gathman, & McPherson, 2010).

Airports are familiar with the issue of rising energy prices and the finite supply of non-renewable energy. Energy costs account for anywhere from 10% to 15% of an airport's operation budget (Lau, Stromgren, & Green, 2010). It is in the best interest of airports to develop means by which they can mitigate their energy use and augment it with renewable sources of energy. Greater emphasis must be placed on constructing facilities that are 'green' and consume as little net energy as possible. (Woodroof, 2009)

Purpose of the Study

The purpose of this study is to generate a snapshot of the adoption rates of solar and geothermal energy systems amongst different categories of airports within the United States, and understand the attitudes and experiences of airport staff toward these technologies. Solar and geothermal power make good candidates for study as both are accessible and viable ways by which an airport can mitigate its energy use. Gaining a better understanding of these technologies through the direct inquiry of individual airports will help to further educate airport staff members that are still considering either technology. Learning what commonalities promote adoption of these technologies will be important in understanding which airports these technologies are best suited.

Significance of the Study

This study will be significant because there is currently a lack of published material that is directed towards airports and the issues of energy mitigation and augmentation. While many airports may already have experience with these technologies, there is currently no research pertaining to what kinds of airports use which technologies, what airport staffs' impressions of these technologies are and what kinds of airports can best benefit from these technologies.

Research Questions

1) Which categories of airports utilize solar and/or geothermal energy?
2) Which variables about airport size, location, amount of geothermal/solar energy access, energy cost, Airport Improvement Plan (AIP) funding and attitude

toward environmentalism most influence the adoption rates of these technologies?

3) What are the attitudes and experiences of airport staff members with these renewable technologies and how do these attitudes reflect adoption rates?

Conceptual Framework

There are many variables necessary for understanding which categories of airports adopt what technologies. These variables require research on the following:

- Determine size characteristics of airports
- Collect data on the energy use of each size of airport
- Determine the use of solar and geothermal energy systems at each kind of airport
- Determine the disposition of airport staff members towards these types of systems
- Determine the AIP funding granted to each airport in the most recent fiscal year
- Determine the disposition of airport staff toward the Leadership in Energy and Environmental Design (LEED) program and what level of LEED an airport may have achieved or is planning to achieve

Definitions

Airport Improvement Program (AIP): A Federal program within the United States to provide grants for the improvement of airports (Federal Aviation Administration, 2010).

Capacity Factor: The ratio of a power plant's electrical generation as compared to the potential electrical generation if the plant was operational for 100% of a given time period (National Resource Council, 2011).

Concentrated Solar Power: These are solar power systems that utilize mirrors and reflectors to focus solar energy at a single point that is connected to the power generation systems, usually a steam system used to power an electrical turbine (Konrad, 2006).

Geothermal Energy: Geothermal energy is derived from the latent heat within the Earth's crust. Geothermal energy systems pump water through piping installed in the ground to absorb heat energy and utilize it in the generation of electricity or for heating. (U.S. Congress, 2007)

HVAC: Acronym for 'Heating Ventilation and Air-Conditioning.'

Large Airport: Heavy airports will have had between 2 million and up to, but not including, 5 million enplanements in 2009.

LEED: "LEED, or Leadership in Energy and Environmental Design, is an internationally-recognized green building certification system. Developed by the U.S. Green Building Council (USGBC) in March 2000, LEED provides building owners and operators with a framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions." (Woodroof, 2009)

Medium Airport: An airport defined as having moderate traffic will have had 400,000 up to, but not including, 2 million enplanements in 2009.

NREL: National Renewable Energy Laboratory

Peak Watt: The term peak watt (W_p) is used to describe the nominal output of a photovoltaic system under specific illumination conditions. Those specific conditions are standardized in order to determine the overall usefulness of a particular system to other systems.

Photovoltaic Solar Power: These are solar power systems that use flat panels designed to absorb, rather than reflect, heat in order to power electrical generators. These systems directly convert solar radiation into electricity with no other step in between (Kreith & Kreider, 2011).

ROI: Return on investment. This is the time required to break even against the initial capital required for development and the yearly operations and maintenance costs required until the breakeven point.

Small Airport: Airports with light traffic are defined as having had 50,000 to 399,999 enplanements in 2009.

Very Large Airport: Very Heavy airports are all those airports that have had 5 million enplanements or greater in 2009.

Assumptions

The following assumptions will be made during this research:

1) That all airports will have the physical ability to incorporate the recommendations, regardless of financial ability, and
2) That research from other fields will be applicable specifically to airport design, and
3) That enplanements is an appropriate metric in describing airport size

Limitations

The following limitations will be in effect during this research:

1) Only airports within the United States will be compared for energy use and size due to limitations on obtaining data from airports internationally, and
2) A floor of fifty thousand enplanements will be used due to email availability and,

3) Unequal numbers of airports per size category due to the limited number of very large and large airports, as defined, are within the U.S.

Literature Review Introduction

The existing literature regarding energy augmentation and reduction specific to airports is not yet very extensive, although interest is rising with the cost of fuel. On the other hand, there is a wealth of general literature on these systems and how these systems relate to general commercial applications. Many of these studies can be extrapolated for use in understanding how solar and geothermal energy systems can be utilized by airports. This literature review will include sources directly related to airports and those which otherwise provide useful information about these two systems.

Airport Energy Use

The U.S. Energy Information Administration (EIA) compiles data on energy consumption within the United States, and separates it based on sector and type of power consumed. The EIA has a category for the transportation sector; unfortunately, these statistics are not narrowed to specifically show airport use (U.S. Energy Information Administration, 2010). The data that is available is useful for determining broadly the types of energy consumed by airports. As it stands, the statistics gathered by the EIA show that the transportation industry consumes about 0.03% of all generated power within the United States (U.S. Energy Information Administration, 2009).

In terms of energy consumption at airports, the available literature does provide some examples of how energy is consumed at specific airports around the world. These examples offer insight into how much energy is used by airports of varying sizes. Sangiorgi, Maellas and Sanglier (2005) found in a small Spanish airport that daily electricity consumption is at around 4,000 kWh per day or about 120,000 kWh per month. Another study that conducted at a medium sized airport in Brazil showed that energy consumption ranged from 150,000 kWh per month to 250,000 kWh per month for this type of airport (Ruther & Braun, 2009).

After reviewing the available literature and information, it is clear that further research is required in order to generate statistics that can correlate airport size to energy consumption. The ability to make such a correlation is important in order to allow the study to be more widely applicable for airports to use. Airports that are considering the use of such technologies will want to know about their success, operational considerations and where they are currently employed. A good portion of the study will be dedicated to determining these statistics.

Renewable Energy Systems

Solar

Solar energy use is one of the more significant sources of clean, renewable energy available to airports within the United States because all airports have access to sunlight. Solar power is also arguably one of the most well known sources of clean, renewable energy. Electricity generated from photovoltaics is completely clean; there are no direct pollution byproducts as a result of the electricity generating process (Woodroof, 2009). The National Renewable Energy Laboratory maintains an interactive web-map cataloging the solar potential of locations through the U.S (National Renewable Energy Laboratory) (See Figure 1). Solar energy can be utilized in many ways to augment and mitigate energy consumption at airports. There is concentrated solar power, photovoltaic cells, solar heat storage, use of biomass and even passive heating and cooling systems. For the purposes of this study, the use of solar energy via photovoltaic cells is the focus. Photovoltaic cells are the most commonly studied type of solar power system and the type that has been specifically studied for use with airports.

Technical discussion

Photovoltaic cells work by directly converting sunlight into electricity, whereas concentrated solar power works by reflecting sunlight onto a single point to drive a conventional steam turbine. Photovoltaic cells are constructed as either “flat plate” or as “concentrators” (Tester, Drake, Driscoll, & Golay, 2005). The most popular, and most well known, is the flat plate style. While not as efficient as concentrators, flat plate systems tend to be more versatile as they can absorb more ambient solar radiation. Flat plate systems are also more easily installed and operated as they are flush with their surroundings and do not to interfere with other structures or installations. There are also a multitude of different manufacturing processes and materials that produce cells of varying efficiencies and cost. It is not necessary to discuss each type as airports will choose the most efficient type of cell for their purposes.

Advantages

The principal advantage to solar power is the ease in which it can be used in a wide variety of situations and in varying scales. Airports make good candidates for the use of solar power as there is a lot of flat surface area available for use. Ruther and Braun (2009) conducted a case study of a medium sized Brazilian airport with regards to solar energy. They analyzed the amount of solar energy available at the airport and used that data to construct a model of the power generating capabilities of that area with several different sizes of solar farms. The purpose of that study was to determine the effectiveness of solar panels in warm climates where the sun shines most of the year. Their findings suggested that a sufficiently sized solar array could meet nearly 100% of the Airport's electricity needs (Ruther & Braun, 2009).

Powering airports directly by means of photovoltaic cells is one way in which solar power can be utilized at an airport. Another, equally important way photovoltaics can be used is when they are attached to specific systems like heating, ventilation and air-conditioning (HVAC) or thermal storage systems. Thermal storage, for example, is a technology whereby solar energy is transferred to a refrigerant and stored for later use (Qu, Yin, & Archer, 2009). These systems are versatile because they allow the stored energy to be used for either heating or cooling, depending on the acute needs of the facility. Qu, Yin and Archer (2009) determined that certain thermal storage systems are between 33% and 44% efficient during the cooling process and between 55% and 65% efficient for heating.

In terms of the economics of photovoltaic systems, the return on investment (ROI) has been steadily increasing, as have the efficiencies of the cells themselves and the overall cost of implementation. The earliest photovoltaic cells had efficiencies of around 6%, and so only 6% of incoming solar energy was converted to electricity (Kreith & Kreider, 2011). Modern photovoltaic systems are now able to achieve efficiencies of up to 16.5%, which is a 175% increase in the amount of solar energy converted to electricity (Kreith & Kreider, 2011). Modern photovoltaic cells have a lifespan of about 25 years and the return on investment (ROI) can be as low as two years (Kreith & Kreider, 2011). The ROI for each airport is specific to the local conditions, however, and may be longer or shorter than average. The cost per peak watt has lowered to about $5 and Kreith & Kreider (2011) foresee that this will drop as low as $1 per peak watt in the near future.

While photovoltaic cells are becoming more affordable, these systems still represent a significant cost in capital for users in comparison to other forms of electricity. The National Renewable Energy Laboratory (NREL) has collected data on the cost per watt of these different forms, and photovoltaic cells come out as the most expensive at around $6 per watt in 2006 dollars. By contrast, coal comes in at a cost of between $1.30 and just over $4 per watt (National Renewable Energy Laboratory, 2010). Fortunately, despite solar photovoltaic's high capital costs, the operation and maintenance costs are some of the lowest amongst all forms of electrical generation (National Renewable Energy Laboratory, 2010). So long as operating costs remain low, photovoltaics can continue to be an economically viable option for reducing an airport's electricity needs and providing for a reasonable ROI.

Disadvantages

Photovoltaic solar has its many advantages, but like all technologies, it has its drawbacks, as well. The most notable drawback for solar photovoltaics is its relatively low capacity factor. Photovoltaic systems have an average capacity factor of 22% (National Renewable Energy Laboratory, 2010). As photovoltaic cells require direct sunlight to operate, cloudy days and times of the year where the duration of sunlight is lower will reduce the amount of electricity these cells can generate. Photovoltaic cells also produce less electricity the less perpendicular the light rays are striking them (Kreith & Kreider, 2011). This is compounded by the fact that there has yet to be devised an efficient and economical way to store excess electricity from solar power. These factors are significant limitations over traditional means of electricity generation, such as coal or oil, which can continue to operate at capacity day or night.

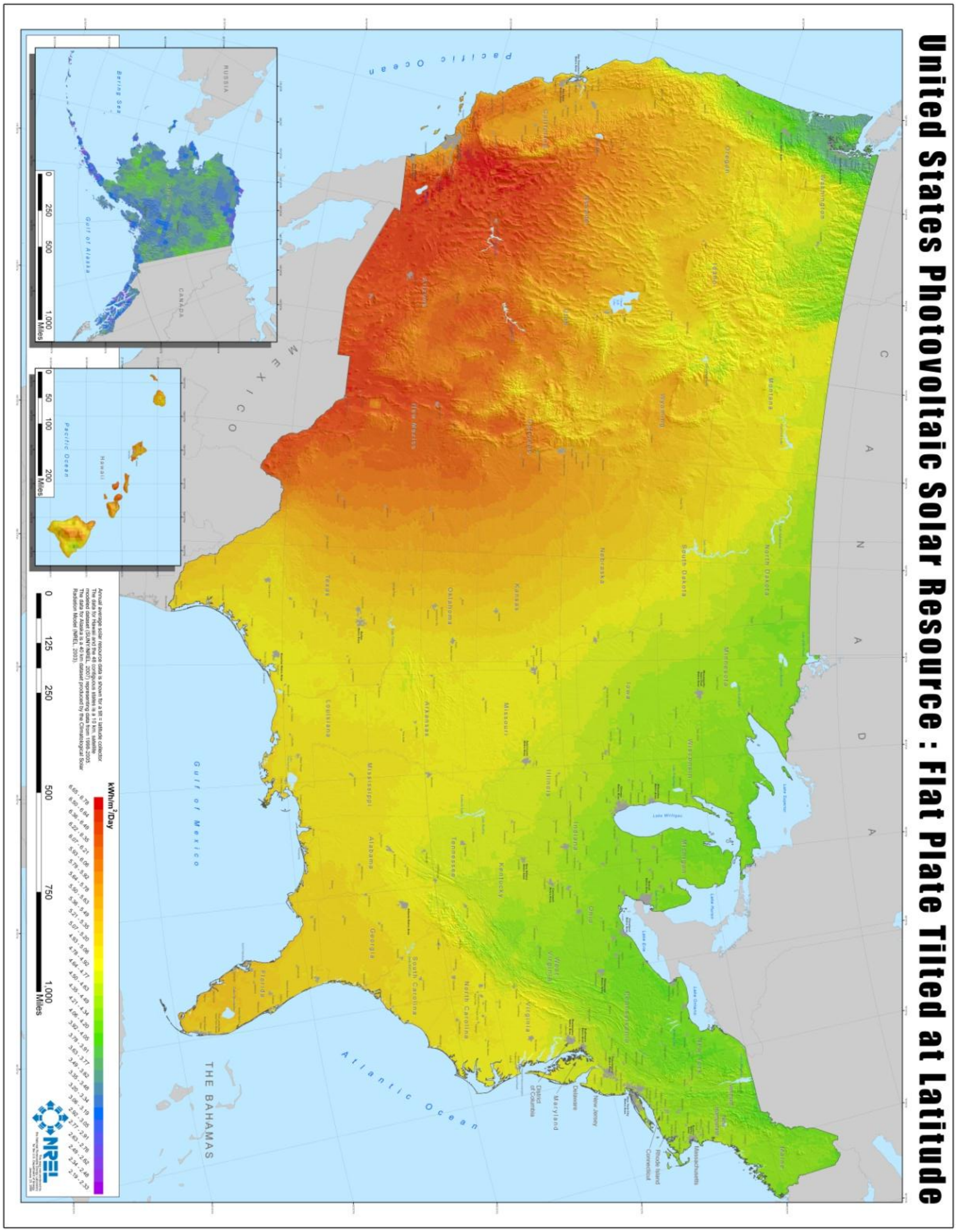

Figure 1. U.S. Photovoltaic Solar Resource Map

Geothermal

Specific studies regarding the use of geothermal power generation at airports are few; however, geothermal power and heating as part of commercial building construction in general appears to be widespread based on the number of research articles available. An article published in 2009 showed the potential of low-grade geothermal to heat structures (Kerrigan, Jouhara, O'Donnell, & Robinson, 2009). The NREL has engaged in extensive study on geothermal potential and use in commercial applications (Anderson, Augustine, & Young, 2010) (Green & R. Gerald, 2006). Geothermal power is an attractive way to mitigate the energy use at airports due to its relatively low cost, it being renewable and also very clean. Geothermal power and heating systems can be used through a complex of buildings or within a single building, which shows its versatility. There are two main types of geothermal sources, and two means by which geothermal energy can be utilized.

Technical discussion

Geothermal systems come in a wide variety of forms, but they all work on the same basic principles. Hot brine is pumped up from beneath the Earth’s crust and used as heating or to generate steam to drive an electrical turbine (Kreith & Kreider, 2011). The brine is then allowed to cool, or run through a cooling tower, and pumped back into the source basin to be re-heated and used again. As for geothermal energy sources, the two main sources are natural sources and enhanced geothermal systems (EGS), sometimes known as hot dry rock (HDR). Natural systems are the most economical, as they require much less capital investment to become operational (Tester, Drake, Driscoll, & Golay, 2005). EGS sources are created by drilling into areas where the rock is sufficiently hot and then introducing brine to allow for extraction of the thermal energy. Besides, the need to introduce brine, EGS functions in the same manner as natural geothermal systems.

Advantages

A chief advantage of geothermal power is its widespread availability through the United States (National Renewable Energy Laboratory, 2009)(See Figure 2). Green and Nix (2006) generated a report on behalf of the National Renewable Energy Laboratory that shows geothermal energy makes up approximately 39.2% of the available energy within the United States. As a comparison, they also showed that petroleum makes up less than 1% of energy availability.

Economically, geothermal systems are very promising. The NREL (2010) estimates the capital cost of geothermal systems from between $2.5 to $3.9 per watt, which is about half that of photovoltaic electricity and within the range of coal at $1.4 to $4.1 per watt. On the other hand, geothermal systems have some of the highest operations and maintenance costs. At between $70 and $170 per kW per year, it is up to five times more expensive to operate as compared to photovoltaics (National Renewable Energy Laboratory, 2010). The higher operating costs of geothermal systems means that their ROI can be significantly longer than photovoltaic systems. Systems associated with high grade sources of geothermal energy can have ROIs as low as five years; however, typical systems will have ROIs around ten years, with low grade systems reaching as high as fifteen years (Tester, Drake, Driscoll, & Golay, 2005).

Despite the longer ROI for geothermal systems, they do possess a marked advantage over photovoltaic systems. The capacity factor of these systems averages 85%, which is significantly better than photovoltaic systems and matches the capacity factor of coal power (National Renewable Energy Laboratory, 2010). The ability to produce electricity or heating steadily throughout the system's operational cycle means that less energy will be required from the grid the airport is attached to and those associated costs will be decreased.

Disadvantages

Outside of the cost of geothermal systems, there are few other drawbacks to its use. Geothermal power is virtually pollution free; with what little pollution produced being easily managed (U.S. Congress, 2007). Geothermal resources also have a tendency to decline in output over time as energy is consumed from the system (Tester, Drake, Driscoll, & Golay, 2005). This is a key consideration for the design of a geothermal system, as energy must be extracted slowly enough to not deplete the resource too quickly. Increased seismic activity is also a consideration, as better geothermal systems are located near seismically active zones (U.S. Congress, 2007). As water is consumed during the operational cycle of the system, hydrostatic pressures within the rock fluctuates and can cause shifting, however, the increased seismic activity is typically imperceptible and can actually help to relieve seismic stress (Tester, Drake, Driscoll, & Golay, 2005).

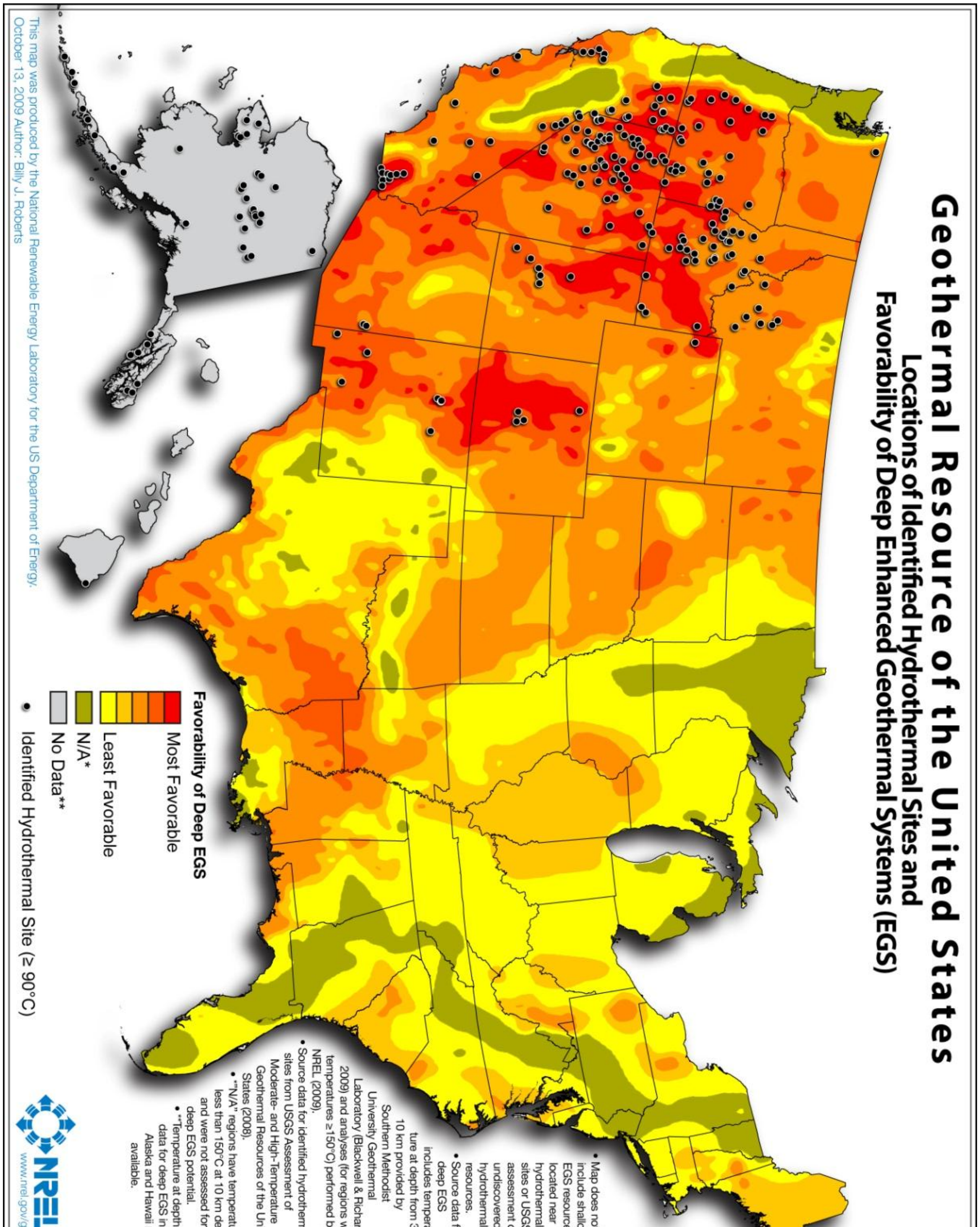

Figure 2. U.S. Geothermal Resource Map

LEED Certification

Another part is to determine the participation of airports with the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program. The LEED program was developed in 2000 to create a standard for new construction projects to measure against in developing environmentally friendly building strategies. LEED certification falls into four separate categories. These are Certified, Silver, Gold and Platinum (U.S. Green Building Council, 2011). Obtaining a specific rating is based upon the number of points achieved based on a list of possible design choices that have been implemented in a structure. Currently, achieving Certified requires from 40 to 49 points, Silver from 50 to 59 points, Gold from 60 to 79 points and Platinum from 80+ points.

Participation in the LEED program was incorporated into the research design in order to provide an objective, descriptive statistic relating an airport's overall commitment to environmental principles to the adoption rates of solar and geothermal systems. Airport staff members were asked to provide written responses detailing their opinions on the LEED program and the systems themselves, but these subjective measures are not easily comparable amongst the sample. The LEED program is available to any airport within the United States, the criteria are the same for all airports and it is simple to catalog airports' participation at each level in addition to participation as a yes or no answer. These features make the LEED program a desirable variable to determine environmental concern among airports.

Summary of Literature Review

Currently, the majority of research articles concerned with solar and geothermal energy do not specifically involve airports. However, the information they provide is essential in understanding the capabilities and possible applications of these technologies. The majority of airports within the United States have access to solar and geothermal energy and both forms of energy have positive ROIs. Solar and geothermal present themselves as viable and economic solutions to the problems of environmentalism and energy consumption as it relates to airport operations.

CHAPTER II

METHODOLOGY OF THE STUDY

Type of Research Design

The research will be a mixed methods design utilizing both quantitative and qualitative data. The variables to be considered are airport size, solar energy availability, geothermal energy availability, LEED participation, solar systems use, geothermal systems use, energy consumption, energy cost, Airport Improvement Program funding per airport and airport staff disposition towards solar and geothermal energy systems. Some of this information, such as energy costs and energy availability, can be gathered from public sources. The remaining desired information will require specific research tools.

Population, Sample and Participants

The population is airports within the United States. U.S. airports were chosen as they are more easily compared against one another and available data will be easier to obtain. They are comparable in terms of federal renewable energy policy and funding. The sample size consists of approximately one hundred seventy airports selected to create a stratified sample based on size and regional location. These airports were categorized by size based on the number of enplanements from 2009 as cataloged by the FAA. The size categories are very large, large, medium and small based on traffic volume. A floor of fifty thousand enplanements was used as most airports below this size had no publicly available email address to send the electronic survey. The initial selection of airports was random based on a desire to obtain four airports per state, with the goal of at least one airport of each size category. This was chosen in order to help maintain adequate numbers of airport type per region. This was done utilizing enplanement data available from the FAA as downloadable via an excel spreadsheet. Once the initial selection was completed, a further sampling was conducted in order to attempt an equal sample size amongst the different size categories. In the case of very large and large airports, there were not enough of these types to reach parity with the other two categories, although a sufficient number exists for comparison.

The method of grouping airports by traffic volume was selected as this more accurately groups airports by their energy needs versus comparing airports by airspace designation or square footage. The enplanement categories were developed based on a study completed by W. Dan Turner (2007) where three enplanement categories were used to compare airports. After eliminating airports with fewer than fifty thousand enplanements in 2009, trend data was analyzed to determine where enplanement levels naturally grouped together, creating the four categories used in this study.

Figure 3. FAA Regions (Federal Aviation Administration, 2009)

Table 1. Airport Categories per Region in Sample

	Sent	Category				
		Very Large	Large	Medium	Small	Total
Region	Alaskan	0	1	1	1	3
	Central	1	1	3	2	7
	Eastern	4	2	9	8	23
	Great Lakes	4	4	5	17	30
	New England	1	2	3	3	9
	Northwest Mountain	3	0	3	13	19
	Southern	8	6	14	7	35
	Southwest	2	5	5	7	19
	Western Pacific	6	7	5	5	23
	Category Totals	29	28	48	63	168

Data Collection, Instruments and Variables

Data collection was accomplished by means of an electronic survey administered through Survey Monkey and emailed to the airports selected as part of the sample population. The survey consisted of sixteen questions designed to gather information on aspects of energy systems use, staff disposition and other variables that are not easily found via public sources. The survey was designed to be straightforward and require minimum effort on the part of the airport staff to complete in order to ensure a high return rate. There are several dependent variables, which are airport size, solar energy availability, geothermal energy availability, LEED program participation, energy consumption, energy costs, energy savings, AIP funding and airport staff comments. The independent variables are solar energy system use and geothermal energy system use. The survey was developed in conjunction with experts in the field.

While all independent variables will be compared against the dependent variables in all permutations, there are specific comparisons that will be of interest. Solar and geothermal energy availability as compared to adoption rates of solar and geothermal systems, energy costs as compared to adoption rates, AIP funding as compared to adoption rates and LEED program participation as compared to adoption rates. These comparisons are of greater interest in determining which airports are likely to adopt solar and geothermal systems in the future and which independent variables have the greatest affect in the decision making process. Of secondary interest are combinations of those stated independent variables against the dependent variables of adoption rates to determine which combination of factors influences the decision making process.

Data Analysis Procedures

The analysis was conducted using a MANOVA of the stated variables with an alpha of .05. Utilizing a MANOVA will have the benefit of compensating for the differing sample sizes amongst the airport size categories. By comparing each of the dependent variables in differing combinations as they relate to the independent variables it will be possible to determine which factors related to different types of airports most influence the adoption of solar and geothermal energy systems, the independent variables. The .05 alpha was selected to be intentionally restrictive in order to draw conclusions with a higher degree of confidence. In addition to the MANOVA, a chi-squared test will be conducted to determine whether the responses of each airport can be attributed to random chance. An alpha of .05 will be used for this test, as well.

The qualitative data on airport staff dispositions and other comments will be used to determine which kinds of airports may be more supportive or less supportive of the two technologies, as well as providing an overall ratio of airport disposition. The open ended response questions will be analyzed to determine the subjective attitudes of airport staff toward each technology. Each response will be noted for its support for or against each technology and the factors driving their decisions. The open ended responses will not be directly comparable to the quantitative data collected; however, these responses will assist in the interpretation of that data.

Anticipated Ethical Issues in the Study

Ethical issues with this study have been minimized as much as possible by following International Review Board and University of North Dakota policies and procedures in regards to research. The identification of those individuals completing the survey will be kept confidential and it is not necessary to disclose their identity in any way as part of the final research. The data requested in the survey is public information as it deals with public-use airports only. Information pertaining to airport staff attitudes and experiences with solar and geothermal systems should pose minimal financial or character risk to the airports that choose to participate in the survey as these individuals will not be identified in the final research. The survey was designed to be voluntary, with the only required piece of information being the airport's International Civil Aviation Organization (ICAO) identifier for classification and quality control purposes. If at any time the participant wishes to discontinue the survey and not submit data, they may do so.

CHAPTER III

RESULTS

Demographics

Of the 178 airports that were surveyed as part of the study, 58 airports responded, which gives a response rate of approximately 32.6% (See Table 2). The Alaskan region had 2 responses for a 66.67% response rate. The Central region had 1 response for a response rate of 14.29%. The Eastern region had 3 responses for a response rate of 13.04%. The Great Lakes region had 13 responses for a response rate of 43.33%. The New England region had 4 responses for a rate of 44.44%. The Northwest Mountain region had 11 responses for a response rate of 57.89%. The Southern region had 9 responses for a response rate of 25.71%. The Southwest region had 7 responses for a response rate of 36.84%. The Western Pacific region had 8 responses for a response rate of 34.78%.

Table 2. Respondents by Region and Category

	Responses	Category					
		Very Large	Large	Medium	Small	Total	%
Region	Alaskan	0	1	0	1	2	66.67%
	Central	1	0	0	0	1	14.29%
	Eastern	1	0	1	1	3	13.04%
	Great Lakes	2	3	0	8	13	43.33%
	New England	1	1	1	1	4	44.44%
	Northwest Mountain	3	0	0	8	11	57.89%
	Southern	2	2	3	2	9	25.71%
	Southwest	0	3	3	1	7	36.84%
	Western Pacific	1	2	1	4	8	34.78%
	Category Totals	11	12	9	26	58	34.52%

The most numerous respondent airports were of the small airport category, coming in at 26 total responses for a response rate of 41.27%. Total responses amongst airports of other sizes were about equal, with 11 very large airport, 12 large airport and 9 medium airport responses. The response rate for these airport sizes was 37.93%, 42.86% and 18.75% respectively.

In terms of the adoption rates for solar and geothermal systems at airports, solar systems were the most popular (See figure 8). Of the 58 airports that responded, 31 (53.45%) indicated that they have installed, or are planning to install, a solar system. Geothermal systems were less popular, with only 12 (20.69%) stating that they have installed, or are planning to install, a geothermal system.

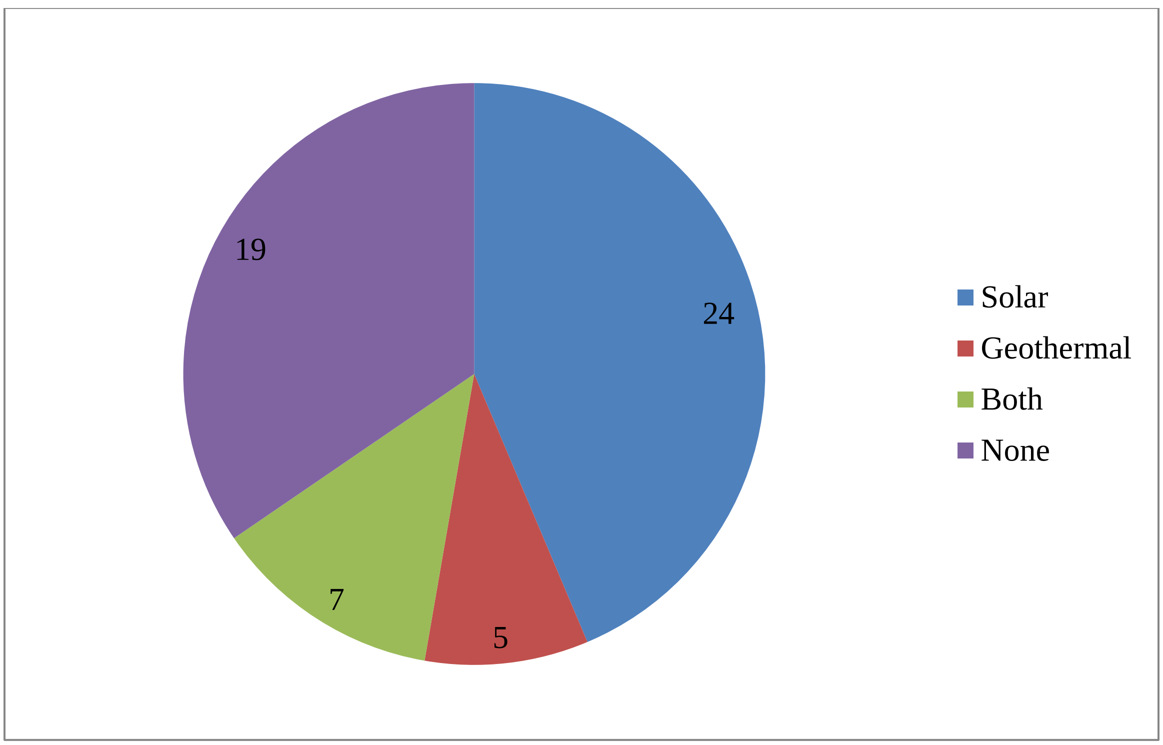

Figure 4. Solar and Geothermal System Adoption Totals

LEED Program

LEED participation amongst responding airports was low. Of the 58 airports that responded to the survey, only 15, or 25.86%, indicated any level of participation in the LEED program. The most popular levels of LEED certification that respondents have attained, or are planning to attain, are Certified and Silver. Each of these levels had 6 respondents. The remaining 3 respondents indicated one of each remaining type of LEED certification, which is one Platinum, Gold and Bronze.

Cost was a major determinant when airports considered participating in the LEED program. Twenty-nine airport staff members provided their opinions on their airports' decisions to become LEED certified or not. For seven of the responses received, the primary factor for their decision not to pursue a LEED certification was the anticipated cost of the program. The other major factor that determined whether an airport would pursue LEED certification was timing, whether or not the certification could be completed as part of new construction. For 12 of the comments received, 41.38%, this was true. The next common response from airport staff members regarding LEED participation was a negative perception of the program.

LEED Participation

While the participation rate of respondents in the LEED program was low, LEED participation is an excellent predictor of an airport's receptivity to solar and geothermal system adoption. Using a MANOVA with an α of 0.05 to evaluate the effect of LEED participation on solar and geothermal system adoption rates, a significance of .002 was returned for solar systems and a significance of .006 was returned for geothermal systems (See Table 3). Pearson's Chi-Squared test supports this, as for both systems the critical value of 3.84 was exceeded, thus showing that the results were not due to random chance (See Table 10). The calculated means for airports without solar or geothermal systems is .145 and .170 respectively. Means for airports with either system are .554 and .529 respectively.

Table 3. LEED Participation as a Predictor of Adoption

	df	Mean Square	F	Significance
Solar Energy Systems	1	1.549	10.491	0.002
Geothermal Energy Systems	1	1.193	8.078	0.006

LEED Level

Compared in the same manner as general LEED participation was the level of LEED certification that the airport has attained or plans to attain. This was to determine if the extent to which an airport was involved in LEED certification has an affect on solar and geothermal system adoption rates. The significance of LEED level sought on the adoption rates of solar and geothermal energy systems is .006 and .000 respectively. Similar to flat LEED participation, the level to which an airport sought or is seeking LEED certification is an excellent predictor of adoption rates. Pearson's Chi-Squared again showed that the results were not due to random chance as the critical value of 9.49 was exceeded in both cases, so this adds strength to the MANOVA results showing the significance of LEED participation (See Table 10). The calculated means for airports without solar or geothermal systems is .468 and 1.393 respectively. Means for airports with either system are .318 and 1.543 respectively. The values for level of LEED participation were based on a scale of 0 through 4. These results indicate that the higher the level of LEED participation for an airport, the greater chance that airport will install either a solar or geothermal system.

Table 4. LEED Level as a Predictor of Adoption

	df	Mean Square	F	Significance
Solar Energy Systems	1	4.548	8.167	0.006
Geothermal Energy Systems	1	7.946	14.268	0

Airport Size

The size of airports surveyed was compared against geothermal and solar system adoption rates in order to determine if size has an impact on those adoption rates. Size is a dependent variable in this case as it is meant to fill in the gaps where unknown or unavailable variables from different airports affect adoption rates. For solar power systems, a significance of .006 was observed for the affect of size on adoption (See Table 5). This indicates a high degree of confidence that size has an impact on whether solar systems are installed at an airport. Again, a Chi-Squared test showed that in relation to airport size, system adoption rates were not due to random chance. Based on the calculated means, larger airports are more likely to adopt solar power systems over smaller airports. The calculated mean for airports that have adopted solar systems is 2.485, where a scale of 1 through 4 was used to describe size, with 4 indicating the largest category of airport. The mean for airports that have not adopted a solar system is 1.432. The standard error calculated for the means of positive solar adoption and negative solar adoption are .241 and .279 respectively.

For geothermal systems, it was found that size has no significant affect on the adoption of these systems. The observed significance based on the responses received was .191, which is well outside the α of 0.05. Additionally, the Chi-Squared result did not exceed the necessary critical value (See Table 10). The mean size for airports that did not adopt a geothermal system is 2.203, with standard error of .166. The mean size for airports that have adopted a geothermal system is 1.714 with a standard error of .329.

Table 5. Size as a Predictor of Adoption

	df	Mean Square	F	Significance
Solar Energy Systems	1	10.321	8.164	0.006
Geothermal Energy Systems	1	2.219	1.755	0.191

Solar Energy Availability

Data provided by the NREL was used to catalog the amount of solar energy available for photovoltaic systems for a given airport. This data was then compared against the adoption rates for solar and geothermal systems in order to determine whether the availability of solar energy was a significant factor. Based on the data provided by the respondents, the availability of solar energy has no significant affect on the adoption of solar systems. A significance of .323 was observed, with means of 4.595 for airports without solar systems and 4.823 for those with or considering (See Table 6). A Chi-Squared test showed that results were due to random chance, the critical value of 67.5 having not been exceeded.

On the other hand, the availability of solar energy was observed to have a significant affect on the adoption of geothermal systems. The observed significance is .024. The mean solar energy availability for airports without geothermal systems is 4.975, while the mean for those with such systems is 4.443. Based on the significance and the means, airports with more access to solar energy are less likely to install geothermal systems. On the other hand, a Chi-Squared test showed these results were likely due to random chance as, also for geothermal systems, the critical value was not exceeded (See Table 10).

Table 6. Solar Energy Availability as a Predictor of Adoption

	df	Mean Square	F	Significance
Solar Energy Systems	1	0.484	0.997	0.323
Geothermal Energy Systems	1	2.269	5.412	0.024

Geothermal Energy Availability

In the same manner that solar energy was cataloged, so was NREL data used to catalog geothermal availability for a given airport. Analysis of the data showed that for solar energy systems, geothermal availability had no significant affect. Significance was observed to be .133 with means of 118.977 for airports without solar energy systems and 140.625 for those with such systems (See Table 7). Standard error is 10.729 and 9.302 respectively.

For geothermal systems, however, a significant affect is observed. The significance is .042, which just meets the 0.05 α standard. Airports that have no geothermal system installed have a mean of 144.602, while those with such systems show a mean of 115.000. Standard error is observed to be 6.392 and 12.680 respectively. These results indicate that while geothermal availability has a significant affect on geothermal system adoption, airports with higher quality geothermal sources are less likely to install such systems. For both systems, however, the Chi-Squared test showed that both results were due to random chance (See Table 10).

Table 7. Geothermal Energy Availability as a Predictor of Adoption

	df	Mean Square	F	Significance
Solar Energy Systems	1	4359.513	2.324	0.133
Geothermal Energy Systems	1	8151.988	4.346	0.042

Utility Rates

The average electricity and natural gas rates were gathered for each airport from NREL data and the U.S. Energy Information Administration and compared against solar and geothermal system adoption rates to determine whether the cost of these utilities has a significant affect on such adoption rates. For both solar and geothermal energy systems, the electricity rate was shown to have no significant affect on adoption rates. The observed significances are .121 for solar systems and .203 for geothermal systems (See Table 8). Similarly, natural gas rates showed no significant effects and so do not appear to influence adoption rates of such systems. The significance for solar systems is .898 and for geothermal systems is .053. In both cases, the Chi-Squared test showed the results were based on random chance, rather than the dependent variable (See Table 10).

Table 8. Utility Rates as a Predictor of Adoption

	df	Mean Square	F	Significance
Solar Energy Systems - Electricity Rate	1	7.098	2.478	0.121
Solar Energy Systems - Gas Rate	1	0.057	0.017	0.002
Geothermal Energy Systems - Electricity Rate	1	4.761	1.662	0.203
Geothermal Energy Systems - Gas Rate	1	13.238	3.898	0.053

Airport Improvement Plan Funding

AIP funding was used to compare the adoption rates of these systems for each airport against the available capital they have received in 2010. In other words, does available capital affect adoption rates? After analysis via the MANOVA, it was observed that AIP funding had no significant affect on the adoption of solar or geothermal energy systems. The respective significances were .361 and .181 and the Chi-Squared results affirmed the null hypothesis (See Table 10).

Table 9. AIP Funding as a Predictor of Adoption

	df	Mean Square	F	Significance
Solar Energy Systems	1	5.37x10^13	0.361	0.898
Geothermal Energy Systems	1	2.702x10^13	0.181	0.672

Variables with Insufficient Data

The remaining dependent variables were not able to have their significance calculated. Utility expenditures, utility consumption, system costs, solar savings and geothermal savings all had too few points of data to allow for comparison. It is unknown, based on the quantitative data collected, whether these variables have any affect on solar and geothermal system adoption rates.

Table 10. Pearson Chi-Squared Values

	Value	df	Critical Value
Solar Energy Systems			
Size	8.012	3	7.82
Solar Energy	49.962	50	67.5
Electricity Rate	58	57	75.606
Geothermal Energy	6.448	7	14.07
Gas Rate	34.555	29	42.56
LEED	5.733	1	3.84
LEED Level	9.637	4	9.49
AIP Funding	49.069	49	66.325
	Value	df	
Geothermal Energy Systems			
Size	4.118	3	7.82
Solar Energy	48.859	50	67.5
Electricity Rate	58	57	75.606
Geothermal Energy	6.839	7	14.07
Gas Rate	27.529	29	42.56
LEED	8.32	1	3.84
LEED Level	13.225	4	9.49
AIP Funding	45.812	49	66.325

Table 11. Means

		Solar Energy Systems		Mean	Std. Error
	Size		No	1.432	.279
			Yes	2.485	.241
	Solar Energy		No	4.595	.173
			Yes	4.823	.150
	Electricity Rate		No	8.047	.419
			Yes	8.921	.364
	Geothermal Energy		No	118.977	10.729
			Yes	140.625	9.302
	LEED		No	.145	.095
			Yes	.554	.083
	AIP		No	6742506.005	3022930.339
			Yes	9145204.949	2621010.773
	LEED Level		No	.345	.185
			Yes	1.045	.160
	Gas Rate		No	9.306	.457
			Yes	9.228	.396
		Geothermal Energy Systems		Mean	Std. Error
	Size		No	2.203	.166
			Yes	1.714	.329
	Solar Energy		No	4.975	.103
			Yes	4.443	.204
	Electricity Rate		No	8.842	.250
			Yes	8.127	.496
	Geothermal Energy		No	144.602	6.392
			Yes	115.000	12.680
	LEED		No	.170	.057
			Yes	.529	.113
	AIP		No	8795924.725	1800962.021
			Yes	7091786.229	3572721.806
	LEED Level		No	.233	.110
			Yes	1.157	.218
	Gas Rate		No	9.863	.272
			Yes	8.671	.540

Airport Staff Member Comments

Solar Adoption

When airport staff members were asked to complete the survey, they were asked to provide their reasoning for the decision whether to adopt a solar power system. The responses received varied from airport to airport, but there were common themes amongst the responses. The emerging themes were cost, timing with new construction, lack of interest and ability to utilize.

The most common theme amongst all responses to this question was cost. Specifically, airports were most concerned with the capital investment required for a solar system and the return on investment. One airport staff member responded with an illuminating explanation in opposition to solar power, which included themes shared by other airports expressing the same,

> Solar energy has a negative cost benefit despite government programs to subsidize it. It's likely that someday it will reach efficiencies that make it viable. The cost of solar remains at three times the cost that most airports can buy from the grid and that assumes that you can sell the emission credits. There is currently no real market outside [State] for these credits and most of the solar salesmen are very misleading on this point. Airport[s] are non-profit so we can't use the producer credit or the emission credits. ... We simply can't invest in technology that is this limited in its usefulness; we would not allow that type of performance out of any of our major systems.

Not all airports shared this negative of solar power. Many of those who completed, or will complete, solar systems found that those systems mitigate their energy requirements and help to save money. An airport staff member that responded positively to solar power had this to say,

> Currently have a 20kW PV array supplemental terminal power. Planning a 500+ kW system which would offset nearly 100% of current usage through net metering. Current system is a "pilot" project to promote sustainability goals of local government. Large system shows a very positive ROI over the projected useful life of [the] system. Positive cash flow in 8 years. 8% ROI over 25 year life expectancy.

The next factor commonly stated was the timing of the project. For some airports, their decision on whether to install a solar system was hinged around the timing of other new construction. Airports that were not looking at solar power for reasons of timing stated that new construction projects were not on the horizon. The results also showed that no airport was in favor of retrofitting existing structures to install solar systems. Those airports that did install solar did so as part of new construction.

Other themes expressed, but which did not represent a large number of responses, were safety, community involvement, public relations and inability to utilize due to location. When expressed, these themes were usually associated with the more common themes of cost and timing. Very few responses listed these themes as the primary decision point for solar energy systems.

Solar Experiences

Airport staff members were also asked to provide their airports' individual experiences with their solar energy systems. They were also asked to provide any insights they may have for airport managers that may be looking at solar as a viable means to offset energy usage and expenditures. There were twelve responses from the airports surveyed that have, or will, install a solar energy system. The responses were varied and there were no themes that emerged.

One theme among staff members was that there were "no problems at all" with their solar energy system. One airport responded by saying that theirs was a, "clean, easy project." For others, lack of FAA guidance was cited as a key experience with the planning of their system. Others advised obtaining guidance from engineers and conducting land use surveys prior to beginning any such project. Only two of the respondents stated that their ROI was not as expected or problematic.

Geothermal Adoption

There were many responses from airports about their attitudes towards adopting geothermal systems. Similar to solar systems, the opinions were widely varied with some common themes emerging throughout. Cost of implementation, timing of construction, lack of interest and feasibility were expressed as the predominant decision making factors for geothermal system adoption.

As in the case of solar, cost was one of the most significant reasons an airport was for or against adopting such systems. There were eight airports which stated the cost of implementation or the ROI was a critical factor. One airport staff member pointed to the importance of government subsidy in their decision to implement a geothermal system, “We are planning on Geothermal heating and cooling. The cost is anticipated to be paid in part by the FAA's VALE program. This system will eliminate the need for one of our boilers and all cooling will be done by geothermal.”

Also an important factor was the feasibility of such system. For six of the respondents, the usefulness of geothermal at their locations or the availability of geothermal resources was the determining factor in not adopting a geothermal system. Next, the desire to complete a geothermal system along with new construction was another theme that emerged. The remaining responses were split between general lack of interest and lack of localized research data.

Geothermal Experiences

A positive theme that emerged was airports which stated that they have had little to no problems with their geothermal systems. When asked about any problems encountered with implementation of their geothermal system, one airport staff member stated, “None. Give it a hard look. Airports have plenty of space for the well or loop systems.” The remaining respondents reported that the need for a re-design, unsuitable location and maintenance costs were problems they had encountered. In regard to maintenance costs, another airport staff member stated, “Balancing the system. Large number of heat pumps increased the number of filters and so increased routine maintenance.

CHAPTER IV

DISCUSSION

Factors Affecting Adoption Rates

LEED Participation

The strongest predictors for the adoption rates of solar and geothermal energy systems were LEED participation and the level of that participation. The results clearly showed that airports that were willing to participate in the LEED program were highly likely to install either a solar or geothermal system. The extent to which an airport participated in the LEED program also spoke directly to an airport's desire to implement such systems.

When comparing these results against the mission of the LEED program, it is easy to see why airports who would seek certification would be receptive to these systems. LEED participation was selected as a variable to help compare the environmental attitudes of the airports surveyed in a way that could be objectively compared. The LEED program is designed around reducing the environmental footprint of new construction projects and being able to generate electricity and heating with a renewable and clean resource meets that goal perfectly. As the level of certification is based upon a total number of points attained from implementing various measures, maximizing the number of points attained is an important factor (U.S. Green Building Council, 2011). The majority of LEED program measures account for 1 to 2 points towards certification. Implementation of a renewable resource, however, can garner between 2 and 7 points towards certification. As one of the largest point earners, it makes sense that renewable energy systems would be looked upon favorably by airports seeking LEED certification.

Size as it Relates to Solar Energy Systems

Size was shown to be a significant factor in whether or not an airport would adopt a solar energy system. Based on the observed averages, the larger the size of the airport the higher the likelihood that airport is operating, or will operate, a solar energy system. This result did not come as a surprise as larger airports typically have greater capital resources available to them that can be utilized to construct solar energy systems. These systems have low maintenance costs, but are capital intensive to construct. As such, smaller airports are less likely to have the need and available capital for a solar energy system.

The size of the airport is also important because of the potential for increased land area to utilize solar cells. The greater the total area of the solar system, the more electricity it can produce. Larger airports tend to have a greater abundance of open space and building rooftops on which to install solar systems. In-fact, a commonly stated location for installation of existing or planned solar systems at airports was on the rooftops of parking garages. Small airports will not have the passenger demand that would necessitate the construction of a parking garage, however, large airports like Chicago O'Hare require large such garages in order to operate at capacity.

Geothermal Energy as it Relates to Geothermal Energy Systems

As would be expected, the availability of geothermal resources at a particular site has a significant affect on whether a geothermal system has been, or will be, adopted. Additionally, the averages support the idea that the greater the quality of local geothermal resources, the more likely an airport is to adopt such a system. There is no hidden message within these results. Higher quality geothermal resources mean that engineers will not have to drill as deeply to obtain the necessary temperatures desired for operation. As system costs increase exponentially with the depth drilled, there is significant incentive to tap into geothermal resources as close to the surface as possible.

Factors Not Affecting Adoption Rates

Solar Energy as it Relates to Geothermal Energy Systems

Analysis of the data via the MANOVA showed that the availability of solar energy at a location had a significant effect on the adoption of a geothermal system. This was a very surprising result, as the availability of solar energy would seem to be irrelevant with regards to the adoption of a geothermal system. Looking at the averages that were calculated, however, it appears that the poorer quality of available solar energy, the more likely a geothermal system was to be considered. This identifies why solar energy would have a significant effect on geothermal system adoption. The lower the quality of solar energy available, coupled with the high initial capital requirements for solar energy systems, would results in a longer ROI for the solar energy system. Geothermal systems would then appear more desirable as even low quality systems are capable of offsetting significant portions of heating, cooling or electricity costs.

On the other hand, the Chi-Squared test did show that the results of the comparison of these variables were likely due to random chance. While it may be logical to assume that a lack of solar energy would lead an airport to obtaining a geothermal energy system, the data does not clearly support this hypothesis. It seems more likely that, given the Chi-Square results and the inverse relationship of energy availability to adoption rates, that solar energy truly does not influence the adoption of geothermal systems.

Solar Energy as it Relates to Solar Energy Systems

This was perhaps the most surprising result. It was found that the availability of solar energy had no significant affect on the adoption of such systems. None of the other variables helped to explain this result. The quality of solar energy available related directly to the ROI of these systems, but this does not appear to have any affect on adoption rates. One possible explanation for these results is that capital costs of the systems coupled with timing of new construction have a greater affect. These two themes were commonly repeated amongst respondents as key decision making factors. Given that solar energy systems are typically very low maintenance, the importance of achieving high outputs may be diminished. If that is true, then the quality of solar energy would indeed not be significant.

Utility Rates as they Relate to Both Energy Systems

The average electricity and natural gas rates were compared against the adoption rates of both types of systems to determine whether these rates had any significant affect on adoption rates. The assumption going into the study was that higher utility rates would incentivize the adoption of such systems, much in the same way that higher gas prices have incentivized the development of hybrid and electric vehicles. The results, however, showed that neither utility rate had any significant affect on an airport's decision to implement either system. While some airport staff members did respond to the survey that low utility prices reduced the need to implement these systems, it appears that this is not a common occurrence among the sample airports.

Airport Improvement Plan Funding

The final variable in which sufficient data was collected for comparison is the level of AIP funding as it relates to the adoption rates of the two systems. The assumption was that an airport's level of AIP funding received would directly correlate to the willingness of an airport to adopt such systems. Given that cost was cited as a principal decision making factor, one would expect AIP funding to have a significant affect. The results showed, however, that this was not the case. AIP funding appeared to be irrelevant amongst the sample population with regards to the adoption rates of either system.

This result is somewhat difficult to explain. AIP funding is available to airports for planning studies, environmental studies, land acquisition and construction projects related to environmentalism. As solar and geothermal systems clearly fall into the latter category, and can be benefitted by the preceding categories, AIP funding would be available for these systems. On the other hand, there are specific federal, state and local grants, bonds and tax incentives related to the implementation of solar and geothermal systems. It is likely that airports would are more concerned with funding from these sources, rather than from the AIP. A number of the responses from airport staff members indicated that government incentive programs outside of AIP funding were key decision making factors.

Implications and Solutions

Based on the results of the survey, it is apparent that airports within the United States are aware of solar and geothermal energy systems as possible solutions for mitigating energy consumption and increasing their reliance on clean, renewable sources of energy. Opinions were mixed in terms of what airports found practical and the level of interest each airport had with each system. The cost of these systems appears to be the most important factor.

Of all written responses, cost was the most common theme. In order to increase the receptiveness of airports to building these systems, this factor needs to be addressed. Government subsidies have helped to increase adoption rates, but it is clear based on the results that increased financial incentive is required. Airports are responsible for maintaining a positive budget and any new capital expenditure must be economically viable. It will not matter how environmentally conscious a particular airport is, if the costs of implementing environmentally friendly systems is prohibitive.

In addition to broader incentives for solar and geothermal systems, the technologies themselves must continue to grow and develop. With efficiencies still only between 10% and 15% for solar photovoltaics, more sophisticated technologies are required to make solar more appealing to airports. Geothermal systems must similarly receive more development attention to utilize available resources, like enhanced geothermal systems, while bringing the initial capital and operating costs down. While these changes will occur naturally as more systems are constructed, continuing research and development is needed, as well.

Future Studies

More research is still needed with regards to utilizing solar power and geothermal systems at airports. Key variables in this study that received too little attention should be studied in more detail. These factors are the costs of these systems compared against the estimated or actualized cost savings of these systems. Those factors would then be more accurately compared against each airport's available capital expenditures budgets, instead of against AIP funding. This would help to more accurately understand the way costs relate to adopting solar and geothermal systems.

Additionally, more study on the energy consumption of airports will help further understanding of what thresholds make these systems viable and practical. Understanding how much energy an airport consumes in day to day operations, and comparing that with the above factors related to operating costs, it will become easier to see where to best implement these systems. This additional study can also help to determine how to best formulate new or modified incentive programs so that airports that have a practical need for such systems are able to reduce the financial burden of these systems so that adoption rates can be increased.

A clearer understanding of the attitudes of airports towards environmentalism would also be a good topic for future study. In addition to using LEED participation as a predictor of adoption rates, this study also sought to use LEED participation as a gauge of an airport's attitudes towards environmentalism. In the latter sense, LEED participation is not a suitable metric as a number of airports were environmentally conscious without desiring to participate in the LEED program.

APPENDIX

Airport Survey on Solar and Geothermal Energy Use

1. What is your airport's identifier?
    a. (Fill in the blank)
2. Has your airport completed or planning to complete a Solar Energy system (e.g. Solar panels, solar powered HVAC, etc.)? If a system has been completed, when was it completed?
    a. Yes, completed
        i. (Year completed)
        ii. (Why?)
    b. Yes, planning
        i. (Why?)
    c. No, not completed or planning
        i. (Why not?)
3. (If #2 was yes) What have the cost savings been/anticipated to be?
    a. (Fill in the blank)
4. (If #2 was yes) What was the cost or the anticipated cost for the program?
    a. (Fill in the blank)
5. (If #2 was yes) What problems have you encountered with the solar system and what advice would you give to other airport managers?

6. (If #2 was yes) What is your impression of the solar system(s) now that they are operational?
7. Has your airport completed or planning to complete a Geothermal Energy system? If a system has been completed, when was it completed?
    a. Yes, completed
        i. (Year completed)
        ii. (Why?)
    b. Yes, planning
        i. (Why?)
    c. No, not completed or planning
        i. (Why not?)
8. If the answer to question 5 was ‘yes,’ what was the cost or the anticipated cost for the program?
    a. (Fill in the blank)
9. (If #6 was yes) What have the cost savings been/anticipated to be?
    a. (Fill in the blank)
10. (If #6 was yes) What problems have you encountered with the solar system and what advice would you give to other airport managers?
    a. (Fill in the blank)
11. (If #6 was yes) What is your impression of the solar system(s) now that they are operational?
    a. (Fill in the blank)

12. Is your airport currently seeking or attained any LEED certification and, if yes, at which level?
    a. Yes, have attained
        i. (Level)
        ii. (Why?)
    b. Yes, seeking
        i. (Level)
        ii. (Why?)
    c. No
        i. (Why not?)
13. How much electricity and gas (heating/facilities related) was consumed by your airport over the preceding fiscal year?
    a. (Fill in the blank)

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